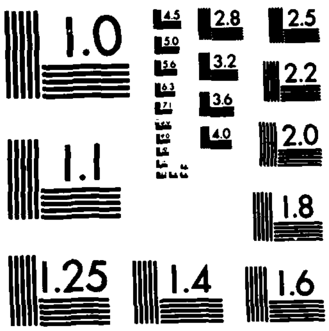
AD-A123 465 LORAN-C EN ROUTE ACCURACIES IN THE CENTRAL APPALACHIAN REGION(U) FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATLANTIC CITY NJ F LORGE NOV 82 1/1

UNCLASSIFIED DOT/FAA/CT-82/32 DOT/FAA/RD-82/24 F/G 17/7 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(14)

DOT/FAA/RD-82/24
DOT/FAA/CT-82/32

Loran-C En Route Accuracies in the Central Appalachian Region

Frank Lorge

Prepared By
FAA Technical Center
Atlantic City Airport, N.J. 08405

November 1982

Final Report

U.S. Department of Transportation
Federal Aviation Administration
Systems Research & Development Service
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. DOT/FAA/RD-82/24	2. Government Accession No. A123 465	3. Recipient's Catalog No.
4. Title and Subtitle LORAN-C EN ROUTE ACCURACIES IN THE CENTRAL APPALACHIA REGION		5. Report Date November 1982
		6. Performing Organization Code ACT-100
7. Author(s) Frank Lorge		8. Performing Organization Report No. DOT/FAA/CT-82/32
9. Performing Organization Name and Address Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 045-390-130
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590		13. Type of Report and Period Covered Final Report April 1980
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Flight tests were conducted in the central Appalachian Region of the United States to measure en route Loran-C position accuracies at low altitudes in mountainous terrain. Receivers were configured to use the Northeast and Great Lakes Chains of Loran-C transmitters during the flights while position information and receiver status were recorded. Comparisons were made between each of the recorded Loran positions and position information derived from the Inertial Navigation System. The results were compared against Advisory Circular (AC) 90-45A accuracy criteria for the en route phase of flight. It is concluded that both the Northeast United States Chain and the Great Lakes Chain meet AC 90-45A en route accuracy criteria over the entire flight test area.

17. Key Words Loran-C Navigation Radio Navigation Low Altitude Navigation	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

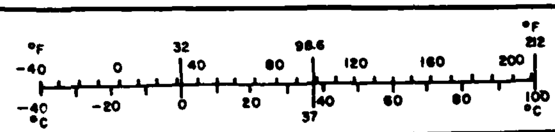


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

OBJECTIVES

This report details a flight test conducted in April 1980 to examine the use of Loran-C in a low altitude mountainous terrain environment. The area selected for the test was the Appalachian region of the United States (U.S.). Specific objectives of the test were:

1. To examine Loran-C performance at low altitude in a mountainous region.

2. To examine Loran-C signal coverage in the Appalachian region.

3. To obtain data on navigation accuracy of Loran-C for en route navigation, using Advisory Circular (AC) 90-45A for accuracy criteria.

4. To obtain comparative data on performance of the Loran-C Northeast U.S. Chain versus the Loran-C Great Lakes Chain.

BACKGROUND

The Appalachian region of the U.S. is a mountainous region in which extensive helicopter operations are conducted. A large amount of this activity is in support of coal mining operations and utilizes relatively unimproved landing areas. The nature of the terrain precludes the extensive use of conventional very high frequency omnidirectional range/distance measuring equipment (VOR/DME) at typical helicopter operating altitudes (less than 5,000 feet above ground level). There is an obvious need in the area for low altitude navigation that is not restricted to the line-of-sight constraints of VOR/DME. Helicopter operators also need direct or point-to-point navigation, such as provided by area navigation (RNAV) systems, to maintain a reasonable level of operating efficiency. A system that can provide these capabilities is Loran-C.

LORAN-C OPERATION.

Loran-C is a navigation system developed by the Department of Defense in the 1950's to meet its operational requirements. Its use was primarily for military purposes until 1974, when it was made available for general civilian use. Since that time there has been increasing interest in the use of this system for aircraft RNAV, principally for low altitude and remote area operations.

Operation of Loran-C is based on low-frequency (100 kilohertz) transmission of timed, coded pulses with strictly controlled parameters. Transmitting stations at specific locations provide coverage of selected areas of the Northern Hemisphere. The propagation characteristics of electromagnetic radiation in this band provide the signal down to the surface, even in mountainous terrain (unlike VOR/DME).

Regional coverage is provided by groups of three to six transmitting stations called chains. Chains are distinguished by their group repetition interval (GRI), which corresponds to the period of the transmission sequence of all stations in the chain.

Each chain consists of a designated master station and several secondary stations. A transmission period begins when the master station sends a set of pulses, coded to identify it as a master. Each secondary station then transmits its signal (figure 1) in turn, after a precisely controlled time delay.

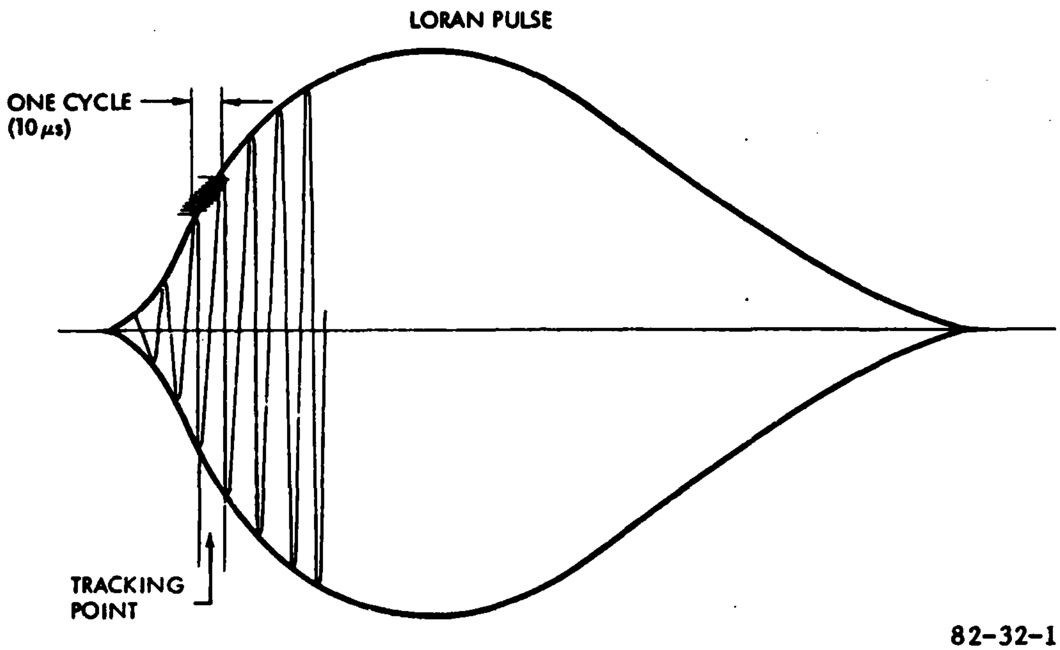


FIGURE 1. LORAN-C SIGNAL WAVEFORM

Position is derived in the receiver by measuring time differences. The master station signal is taken as a reference, and time is measured from it to each of the secondary signals. The measured time difference corresponds to the distance of the receiver from the transmitter and lies along a line of position (LOP) of constant time differences. Measured time differences from a second transmitter provide a second LOP; the intersection of these lines is the Loran-C position, which is available to the operator as a latitude/longitude (lat/lon). Because it works in lat/lon coordinates to perform navigation functions, it is inherently an RNAV system.

Coverage of the Appalachian region is provided by the Northeast U.S. Chain, GRI 9960 (figure 2), and also by the Great Lakes Chain, GRI 8790 (figure 3). The Northeast U.S. Chain consists of a master station in Seneca (New York), with secondaries in Caribou (Maine), Nantucket (Massachussetts), Carolina Beach (North Carolina), and Dana (Indiana). The Great Lakes Chain consists of a master in Dana, and secondaries in Seneca, Malone (Florida), and Baudette (Minnesota). For a more detailed description of Loran operation, the reader is referred to the "Loran-C User Handbook," U.S. Coast Guard Publication COMDTINST M16562.3.

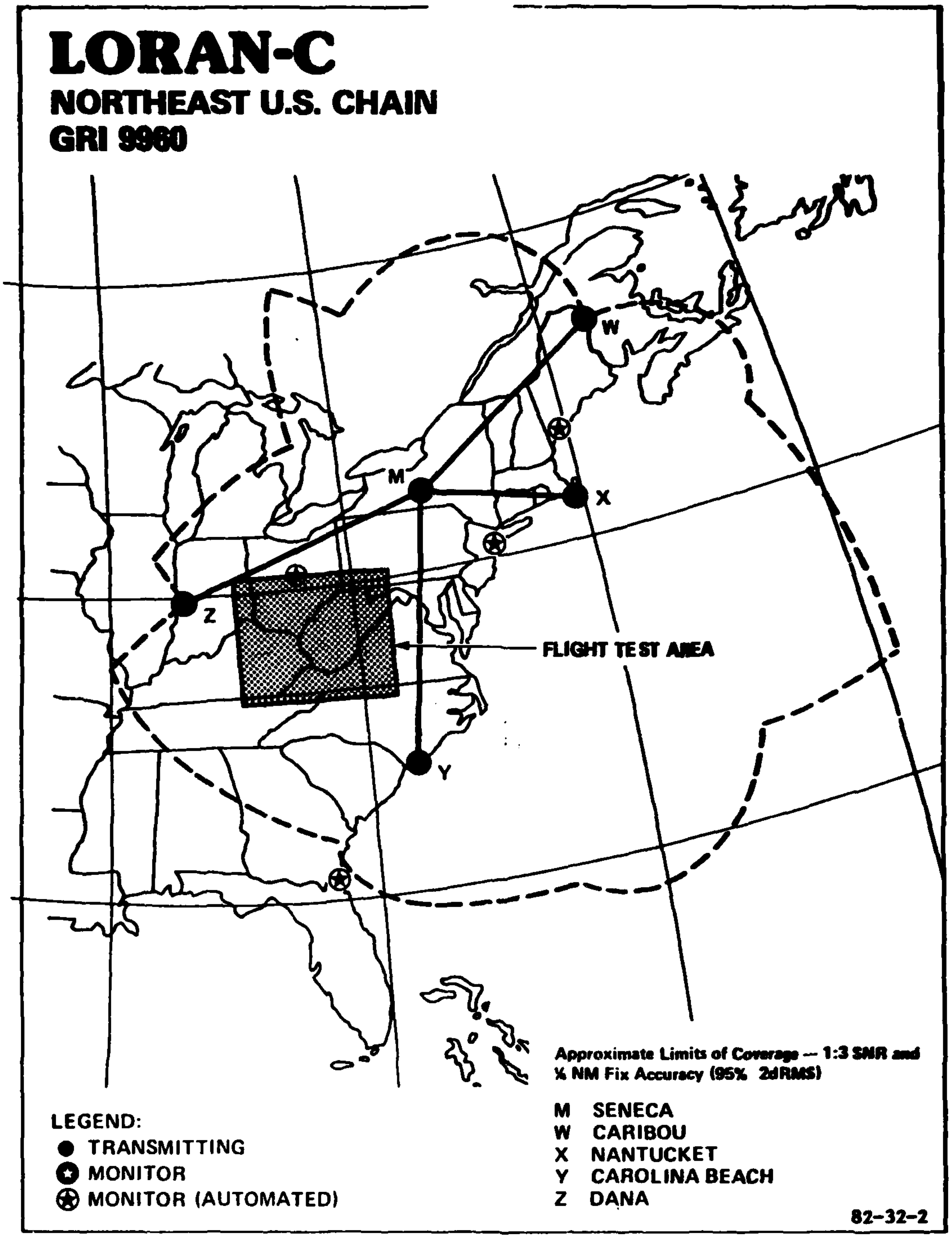


FIGURE 2. NORTHEAST U.S. LORAN-C CHAIN (GRI 9960)

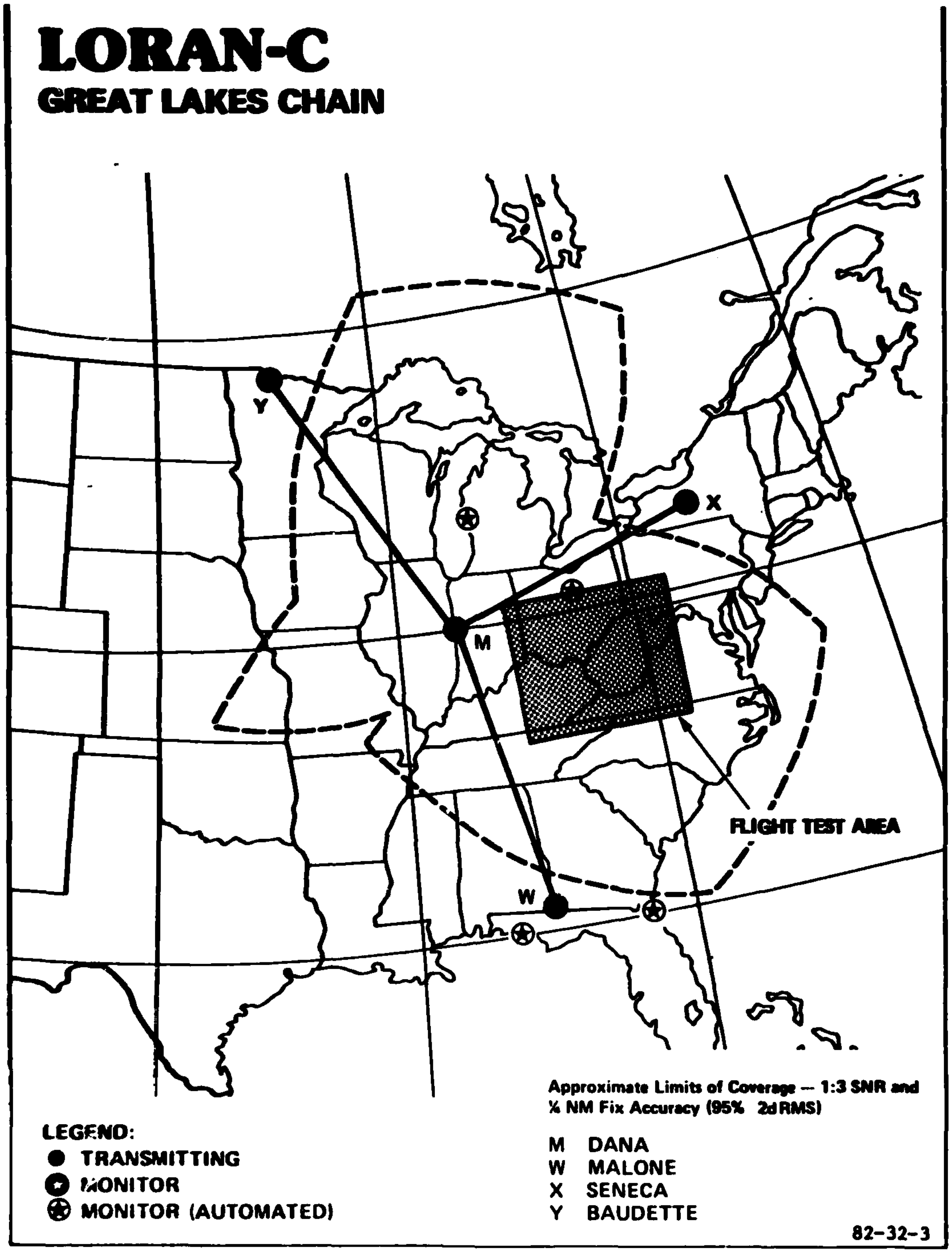


FIGURE 3. GREAT LAKES LORAN-C CHAIN (GRI 8970)

EQUIPMENT DESCRIPTION

Data were collected aboard a Convair CV-580 (figure 4) which carried project equipment designed to record Loran-C parameters and aircraft avionics signals. The aircraft is a twin-engine turboprop equipped with an inertial navigation system (INS).

Data collection was directed by a Norden PDP 11/34M minicomputer. This is a militarized version of the Digital Equipment Corporation's PDP 11/34 processor with 32,768 bytes of memory, a floating point processor, and a pair of militarized floppy disk drives. The system was configured to collect Loran-C data and aircraft state information once each second for storage on floppy disks.

Aircraft signals are interfaced with the computer through an aircraft system's coupler (ASC). This unit samples aircraft signals from the various sensors and flight instruments and converts them to a format suitable for computer input. It also provides timing for the collection and correlation of data.

Also onboard were two TDL-711 Loran-C Micro-Navigators (figure 5) built by Teledyne Systems. Each consists of a control display unit (CDU), a receiver computer unit (RCU), and an antenna coupler unit (ACU). The antennas were mounted on top of the airplane, as shown in figure 4, to receive Loran-C signals, which are amplified and filtered in the ACU. The RCU then processes the signals to determine position. The CDU is used to display position and waypoint information, and to allow the operator to input information and select displays. The project data collection installation is pictured in figure 6.

The INS onboard was a Litton LTN-51. It consists of a navigation unit, CDU, and a mode selection unit (MSU). Display of position and other navigation information is accomplished by the CDU. The CDU also allows input of commands as well as position and waypoint information. The MSU is used to select various modes of operation including alignment and navigation modes.

The nature of INS operation leads to drift errors during flight which will produce errors in derived position. The LTN-51 INS has drift rates which may approach 1 nautical mile (nmi) per hour. Compensation for drift of the INS was accomplished during post-flight processing using the method described in appendix A. The corrected INS was used as a position reference to measure Loran magnitude errors. The uncertainty of the corrected INS was ±0.3 nmi, which exceeds that expected of the Loran. However, because the combined Loran and INS errors were not expected to exceed the 1.5 nmi limit, the INS system was sufficient to measure compliance with AC 90-45A. Since the system does introduce uncertainty in measured error terms, the results should not be interpreted as absolute Loran accuracies.

DATA COLLECTION

Data collection, as directed by the Norden computer, consisted of sampling aircraft and project signals approximately once each second. The ASC received signals identical to those sent to the cockpit and converted them to digital format for input to the computer. These data were stored on floppy disks for later data reduction. Flight data parameters recorded are listed in table 1.

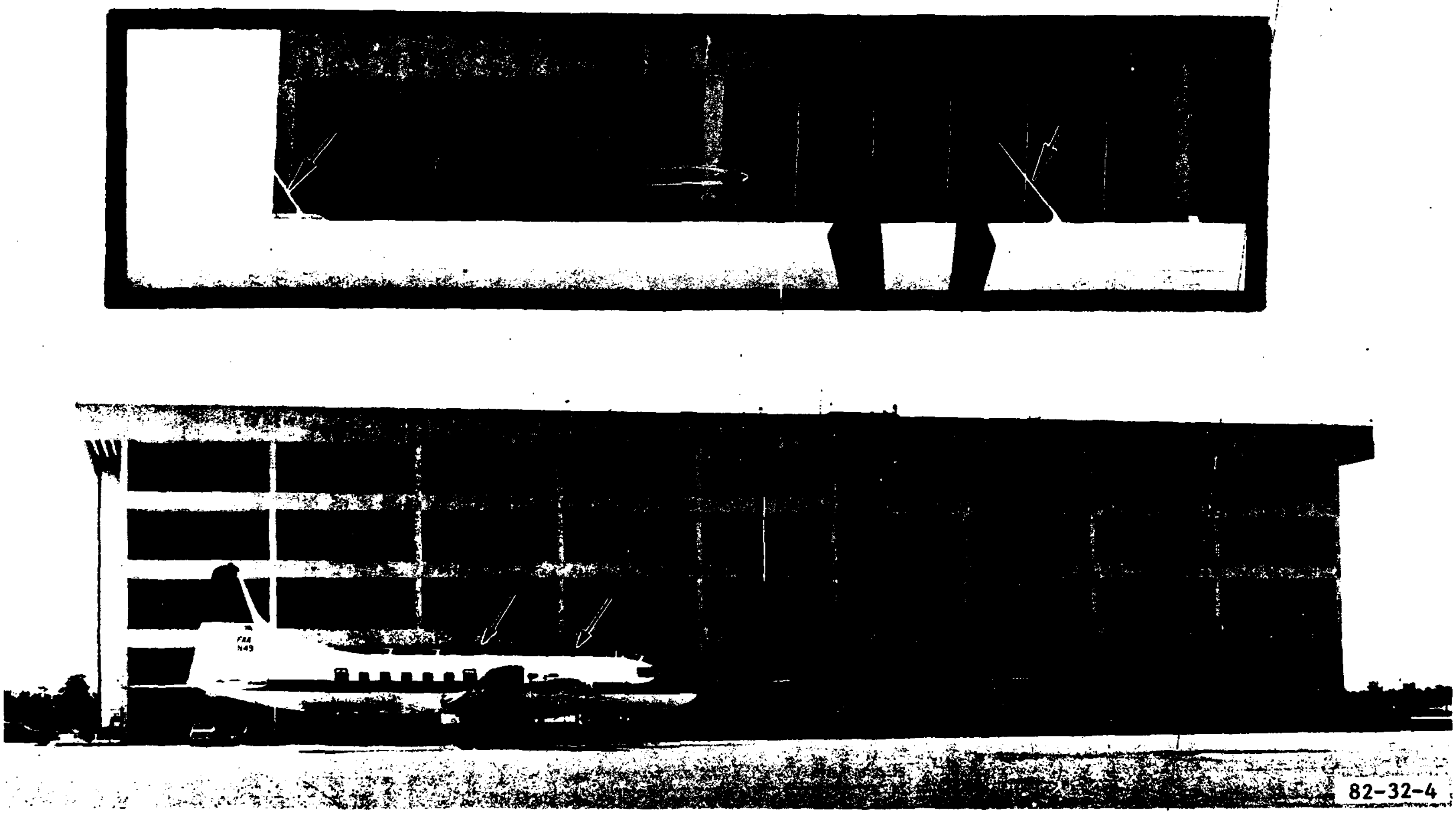


FIGURE 4. CV-580 TEST BED AIRCRAFT

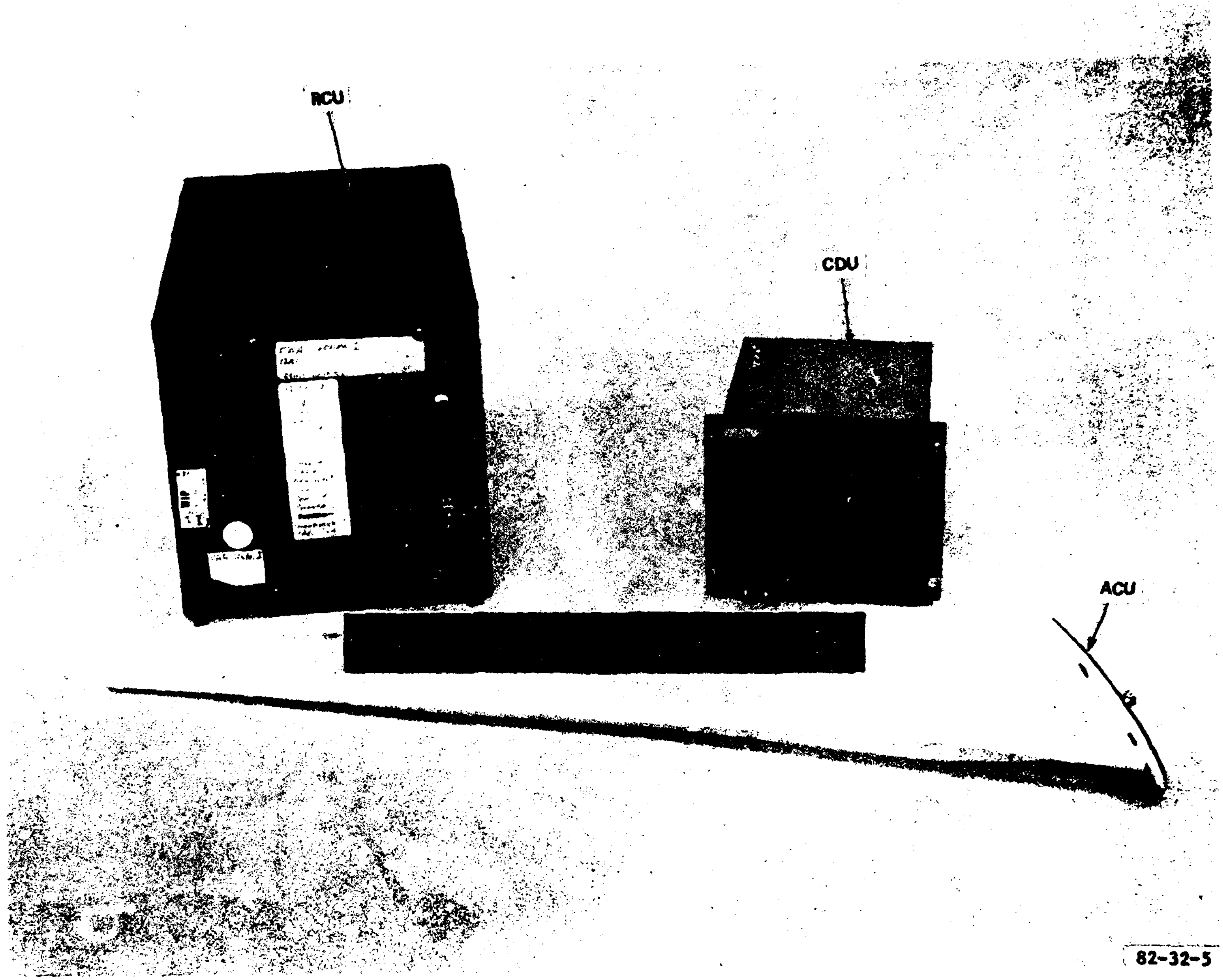


FIGURE 5. TDL-711 LORAN-C MICRO-NAVIGATOR

FIGURE 6. DATA COLLECTION EQUIPMENT ON CV-580

TABLE 1. RECORDED FLIGHT DATA PARAMETERS

Flight Parameters

Time
Pitch attitude
Roll attitude
Magnetic heading
Flight director commands and modes
True airspeed
Barometric corrected altitude
Vertical speed
Radar altitude

Loran-C Parameters

Latitude
Longitude
Delta latitude
Delta longitude
Time difference A
Time difference B
Track status
SNR
Crosstrack Distance
Along-track Distance
TO waypoint
FROM waypoint

INS Parameters

Latitude
Longitude
Ground speed
True heading
Wind speed
Wind direction

FLIGHT TEST PROCEDURES

Flight tests were conducted during the week of April 14, 1980, using the CV-580, designated N-49, based at the Federal Aviation Administration Technical Center. The airplane was flown to Charleston, West Virginia, for four data collection flights of approximately 4 hours each.

The area from latitude N 36.5° to N 40.0° and longitude W 79.0° to W 84.0° was divided into quadrants, each of which was the subject of one flight. The quadrants approximated northeast, northwest, southeast, and southwest sectors. Flightpaths crossing each quadrant were flown at an altitude of about 1,000 feet above ground level. The routes flown are shown in figure 7.

Each flight consisted of a series of legs flown from one waypoint to another. Each waypoint was a geographic reference of known coordinates. As the waypoint was overflown, the pilot depressed a button which caused an event mark to be recorded by the data collection equipment, along with the time, for correlation of recorded aircraft position and flight data. These event marks were used in the data analysis to provide an approximate correction for INS drift. A list of the waypoints defining flight legs appears in table 2.

To provide navigational information, the TDL 711 must be configured to use signals from three stations in the same chain, forming a primary triad. It also allows selection of a backup station in the same chain, so that all four signals may be tracked simultaneously. Selections of primary triads and backup stations were made according to geometrical considerations and signal availability. Geometrical constraints require that intersecting LOP's cross at an angle as close to 90° as possible, and not less than 30°. Based on this, the primary triad for the flight test area, when using the Northeast U.S. Chain, utilizes Seneca, Carolina Beach, and Dana. Since these stations are also the closest ones to the flight test area, they were expected to provide the strongest signal. This triad was, therefore, chosen as the primary. Based on previous experiences, the Caribou signal would not be available, so Nantucket was chosen as the fourth station for the receiver to track.

The Great Lakes Chain provides good geometry over the flight test area for all possible triads. Signal strength was the determining factor. Dana, Malone, and Seneca were used as the primary triad because they were closest; Baudette was used as a backup.

During the flight test, one receiver was configured to receive the 9960 Chain with Seneca, Carolina Beach, and Dana as the prime triad, and the other was configured to use the 8970 Chain with Dana, Malone, and Seneca as the prime triad. Receiver configuration was maintained for the duration of the test to insure that receiver specific performance characteristics did not influence the effects of geographical position on the data.

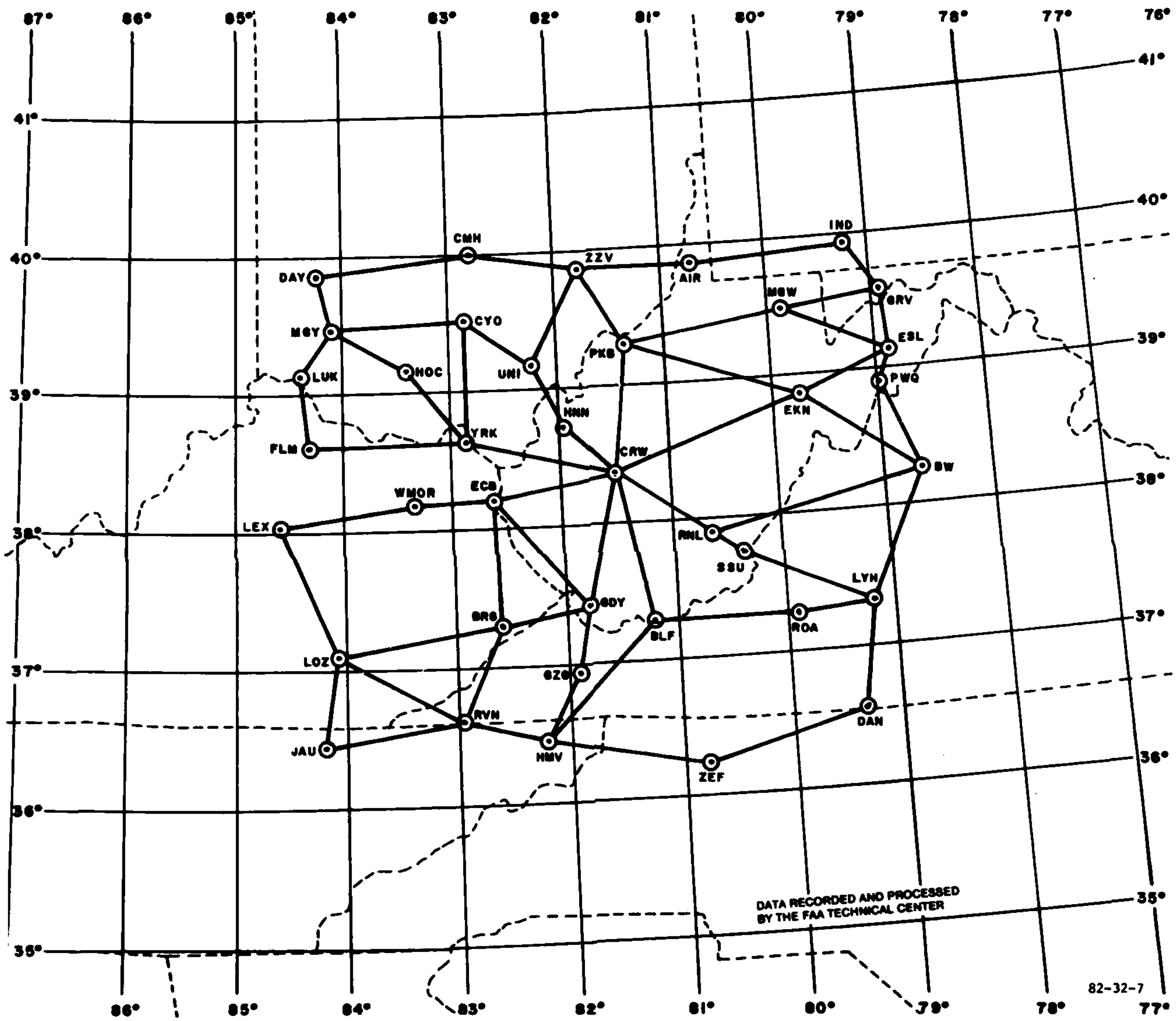


FIGURE 7. FLIGHT TEST PATTERNS

TABLE 2. WAYPOINTS ALONG TEST ROUTES

Waypoint	Type Facility	Ident
Charleston	VORTAC	CRW
Grundy	RBN	GDY
Glade Springs	VORTAC	GZG
Holston Mountain	VORTAC	HMV
Rogersville	RBN	RVN
Jacksboro	RBN	JAU
London	VORTAC	LOZ
Lexington	VORTAC	LEX
Morehead	RBN	WMOR
Newcombe	VORTAC	ECB
Whitesburg	VORTAC	BRG
Rainelle	AB VOR	RNL
Bridgewater	RBN	BW
Lynchburg	VORTAC	LYH
Danville	VOR	DAN
Zephyr	RBN	ZEF
Bluefield	VORTAC	BLF
White Sulphur Springs	TVOR	SSU
Roanoke	VORTAC	ROA
Parkersburg	VORTAC	PKB
Zanesville	VORTAC	ZZV
Bellaire	VOR	AIR
Indianhead	VORTAC	IND
Grantsville	VORTAC	GRV
Morgantown	VORTAC	MGW
Elkins	VORTAC	EKN
Kessel	VORTAC	ESL
Dorcas	RBN	PWQ
York	VORTAC	YRK
Falmouth	VORTAC	FLM
Cincinnati	RBN	LUK
McGuire	VORTAC	MGY
Dayton	VORTAC	DAY
Columbus	RBN	CMH
University	RBN	UNI
Circleville	RBN	CYO
Hillsboro	RBN	HOC
Henderson	VORTAC	HNN

DATA ANALYSIS

Comparative data were analyzed from the dual Loran-C receivers. The accuracy of each was determined with respect to position information derived from corrected INS data.

INS correction was accomplished by approximating the INS drift. This approximation was derived from the difference between the recorded INS position and the known position as the plane flew over a geographic reference and the event marker was activated. INS drift was approximated by the change in the differences over successive reference points. The drift was then compensated for by adding a correction factor to each recorded INS position. Based on examination of INS drift and the frequency of the INS updates, corrected INS position was estimated to be accurate within 0.3 nmi of the actual position. An analysis of INS drift for one flight and a further explanation of the drift correction technique are presented in the appendix.

Corrected INS position information was used as the reference for comparison of Loran-C derived position. Loran-C errors, as compared to this position, were sorted into latitude and longitude errors for sectors in the flight test area. Each sector extends for 0.5° of latitude and 0.5° longitude. Northing and easting errors were characterized by a mean and standard deviation in nmi for each sector. Total measured Loran-C error is defined as the mean plus two standard deviations. It is an estimated error level which is not expected to be exceeded 95 percent of the time.

AC 90-45A REQUIREMENTS

En route accuracy criteria are set for RNAV systems by AC 90-45A. Maximum allowable errors are 2.5 nmi crosstrack and 1.5 nmi along-track. The crosstrack term includes flight technical error (FTE), specified to be 2.0 nmi for the en route case, which is combined with navigation system errors in a root sum square (rss) manner. Reducing the error budget by the stated FTE value leaves 1.5 nmi for navigation system error in both crosstrack and along-track directions.

Measured Loran error consisted of northing and easting error components. When these components are added vectorially, they will produce a vector whose magnitude is the worse case contribution by the Loran to total system crosstrack or along-track error. Depending on the direction of flight, this vector, when resolved along the crosstrack and along-track axes, results in varying errors in the cross-track and along-track directions. It is, therefore, this magnitude which must be below 1.5 nmi to meet the error budget established.

RESULTS

LORAN-C ACCURACY RESULTS.

Measured Loran errors are presented for GRI 9960 and GRI 8970 derived positions in figures 8 and 9, respectively, for each sector in the flight test area. Each

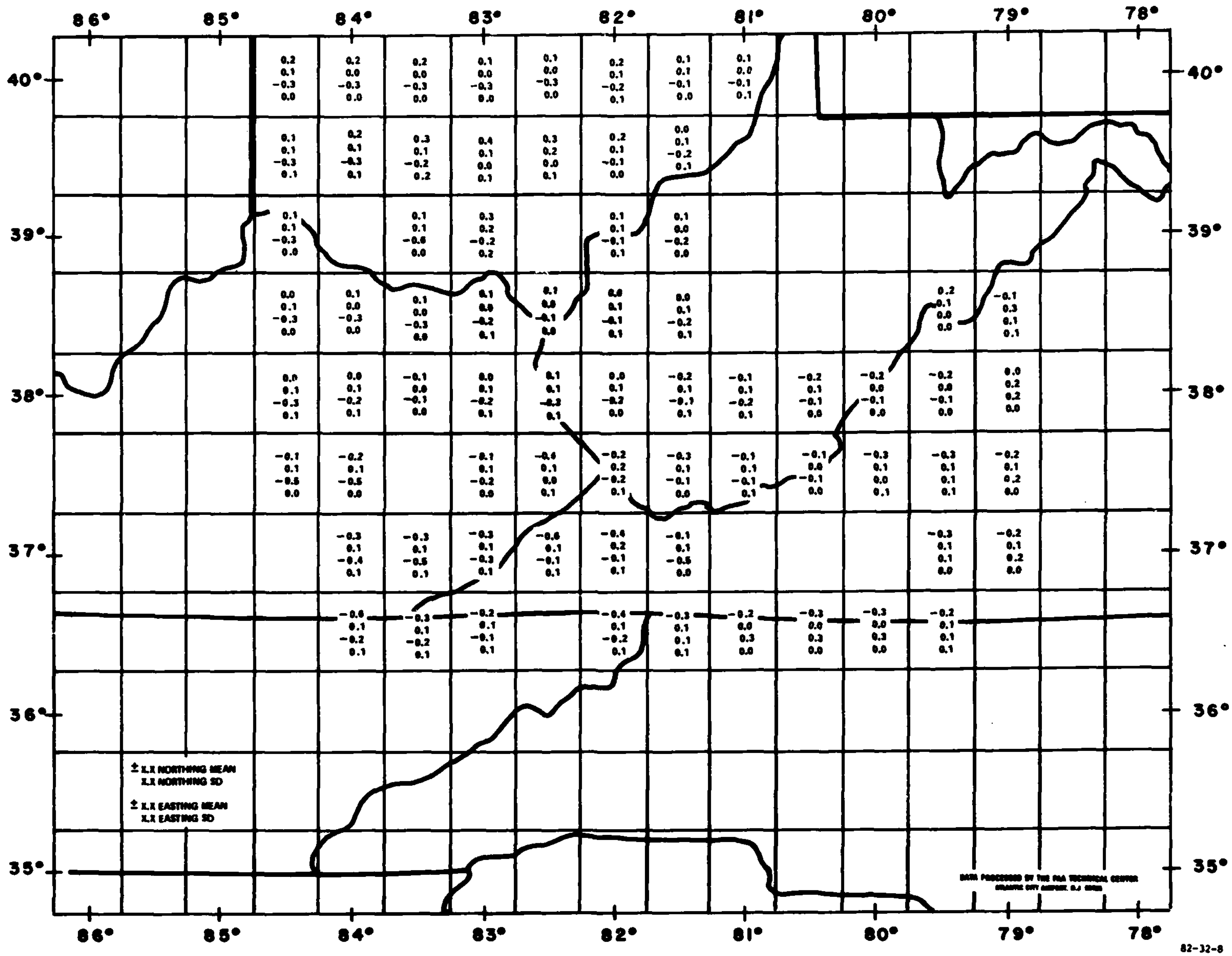


FIGURE 8. MEASURED LORAN-C NORTHING AND EASTING ERRORS FOR NORTHEAST U.S. CHAIN

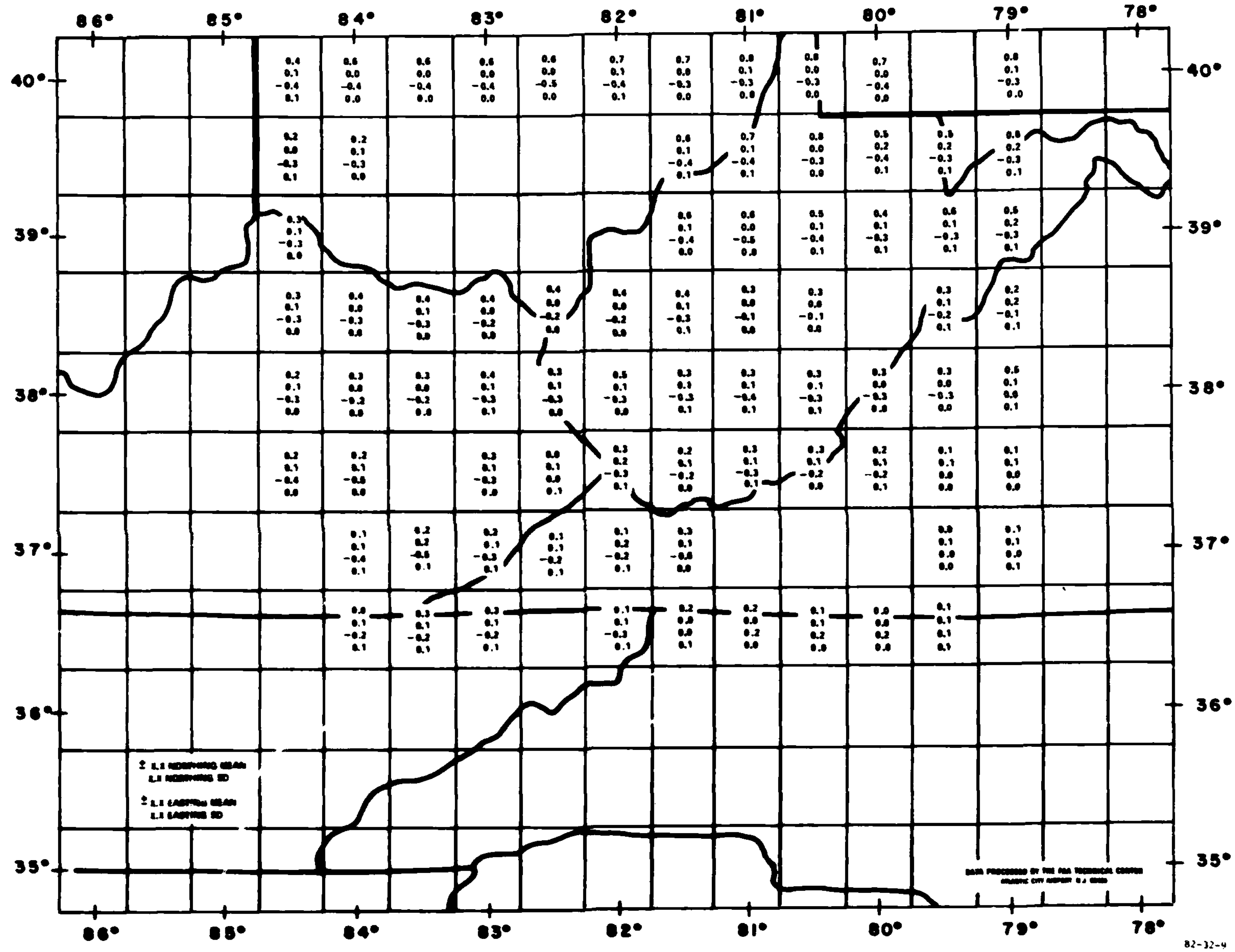


FIGURE 9. MEASURED LORAN-C NORTHING AND EASTING ERRORS FOR GREAT LAKES CHAIN

sector extends for 0.5° latitude and 0.5° longitude. Blanks indicate that too few data samples (under 100) were collected in that sector to be statistically significant. Data have been rounded to one decimal place.

Two important trends are discernible. The most apparent is the increase in northing error when using the 8970 Chain (figure 9) to the north and northeast portions of the flight test area. Also significant is the fact that northing errors are smaller for all sectors for the GRI 9960 derived position than for 8970 in areas north of N 37.5° latitude.

Data are generally consistent over the flight test area for both chains. High standard deviations appear in several entries in figures 8 and 9. In all cases where entries appear in corresponding locations of both figures, comparably large standard deviations are shown. It is believed that an error in the corrected INS, which is common to measured Loran error for each chain, is the source of these larger variances. They may also be the result of a poor event mark which adds a bias that changes with time. The error source cannot be completely determined from available data. Since corrected INS accuracy is ±0.3 nmi, its effect does not preclude use of the data to verify compliance with AC 90-45A.

Northing and easting Loran errors were added in an rss manner to determine the magnitude of total measured Loran error. These data are presented in figure 10 for the GRI 9960 Chain, and in figure 11 for the GRI 8970 Chain. These values represent the maximum crosstrack or along-track errors, depending on the direction of flight. The GRI 9960 Chain errors (figure 10) contain no entry that exceeds 1.2 nmi. The GRI 8970 Chain errors (figure 11) contain no entries which exceed the 1.5 nmi maximum.

LORAN-C COMPARATIVE RESULTS.

Results of the comparison of both chains being evaluated are presented in figure 12, which shows the difference in latitude and longitude means in solutions derived from each chain for each sector of the flight test area. A negative number indicates that the solution provided by the Great Lakes Chain is north (for latitude) or east (for longitude) of the solution provided by the Northeast U.S. Chain. The equations used were: northing difference = 9960 latitude mean - 8970 latitude mean, easting difference = 9960 longitude mean - 8970 longitude mean.

Results show greater differences in latitude (northing) solutions than longitude (easting) solutions. Northing differences above N 38° latitude increase to the east, but the trend gradually reverses itself south of this line. Northing differences in the south of the test area decrease progressively east of W 81° longitude, and exhibit a slightly increasing trend west of this line. Easting differences increase to the east and north.

Loran accuracy is affected by local warpages in the Loran grid. Geometrical effects and propagation characteristics combine to cause variations in performance in different areas. Propagation time from signal transmission to reception is a function of the earth's conductivity underlying the signal path. It directly affects time differences from which the position is calculated. It also affects the SNR ratio, which determines how well the receiver can find the tracking point of the signal at which time differences are measured. Transmitted power and distance from the transmitter also affect SNR, as does local interference in the Loran frequency band.

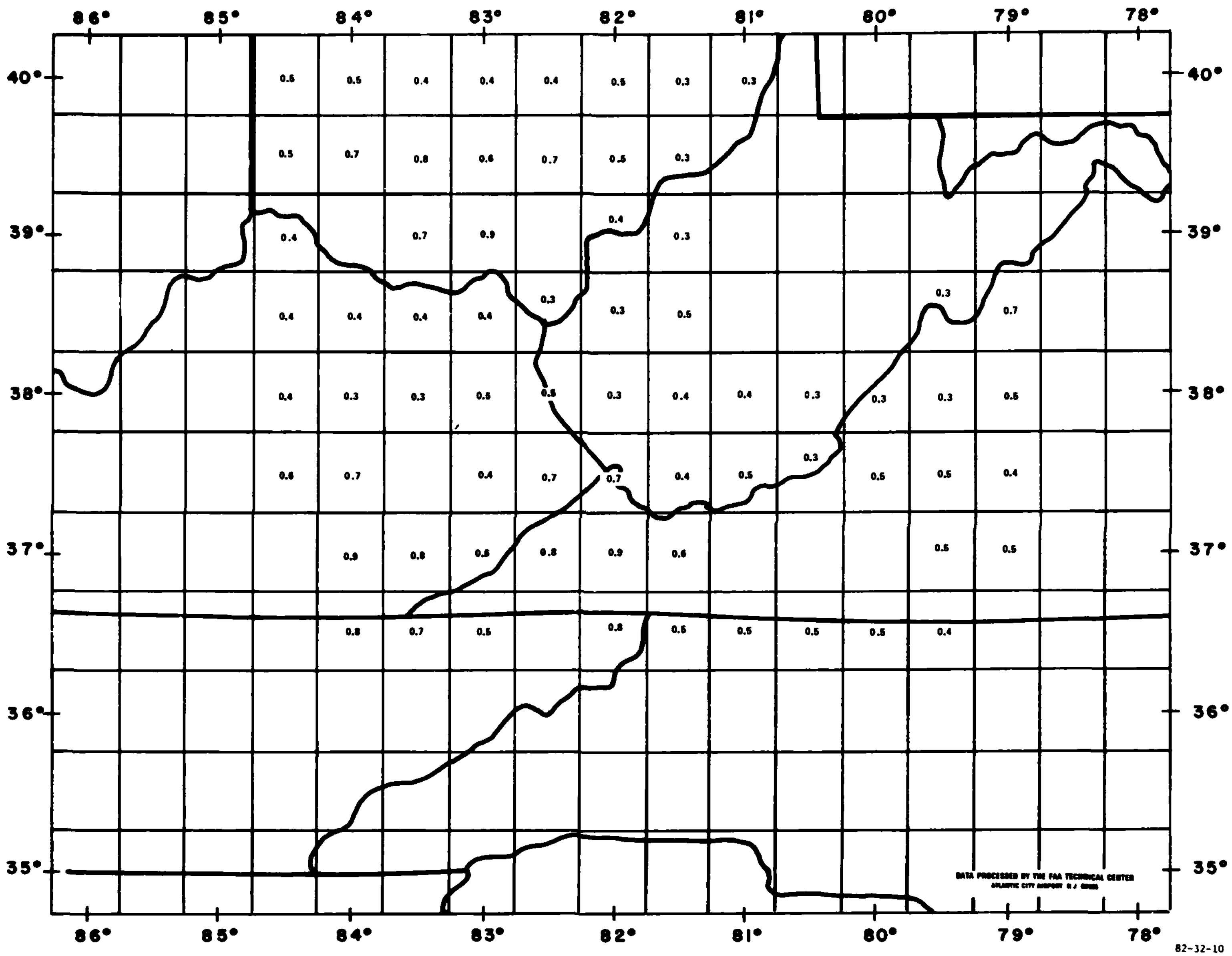


FIGURE 10. TOTAL MEASURED LORAN-C ERROR FOR NORTHEAST U.S. CHAIN

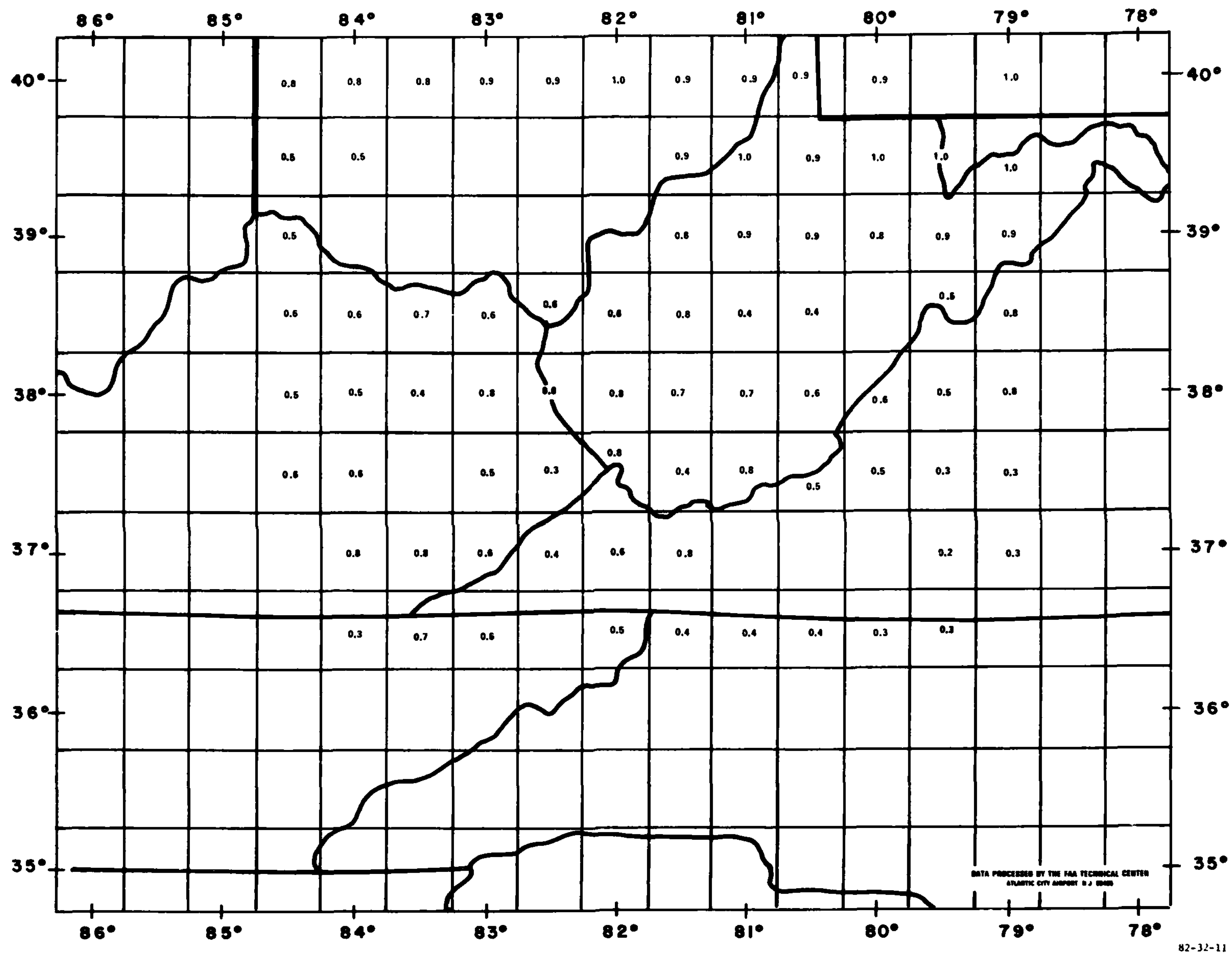


FIGURE 11. TOTAL MEASURED LORAN-C ERROR FOR GREAT LAKES CHAIN

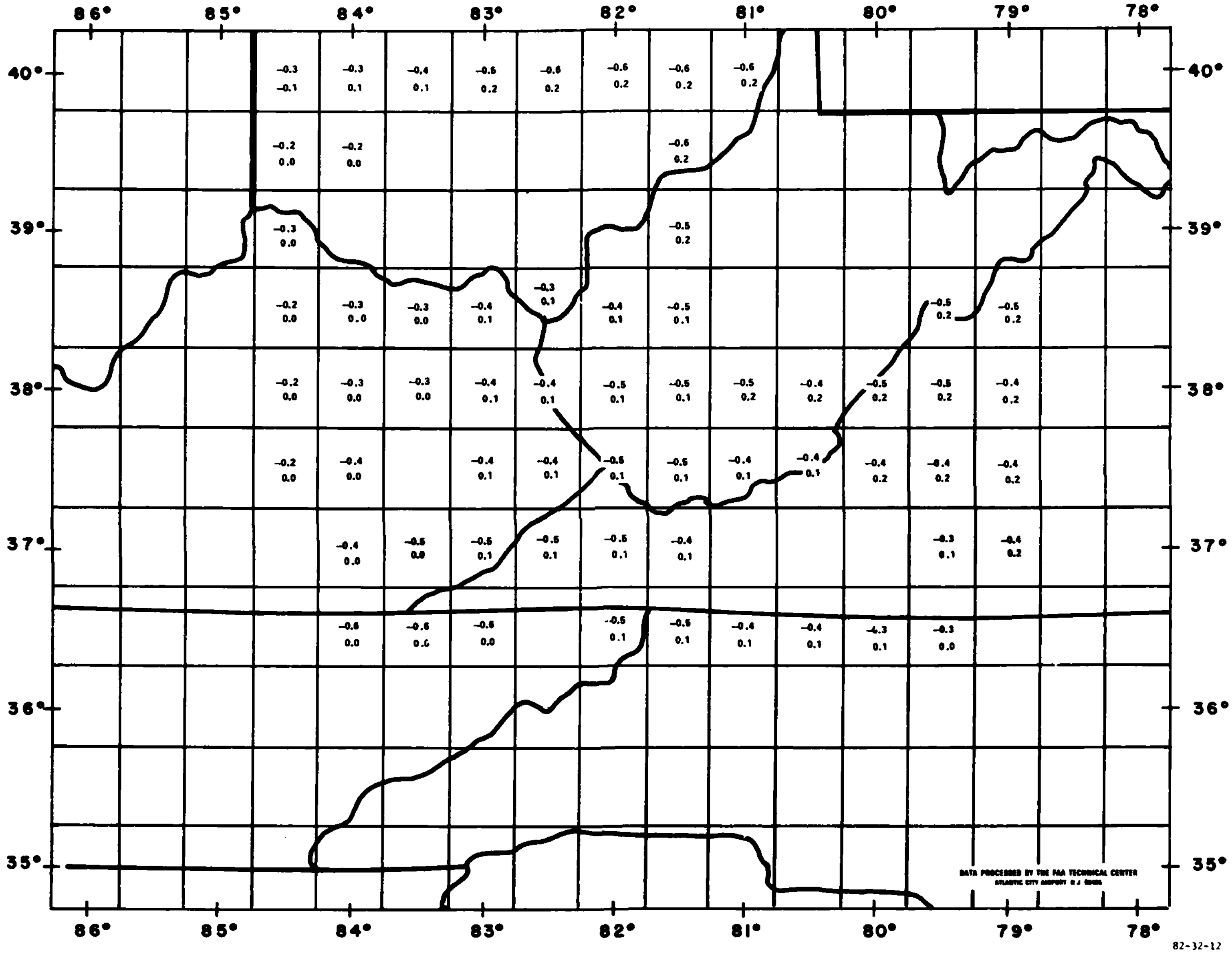


FIGURE 12. NORTHING AND EASTING DIFFERENCES BETWEEN THE NORTHEAST U.S. AND GREAT LAKES LORAN-C CHAINS

The geometrical effect mentioned above has to do with the angle of intersection of LOP's and receiver precision in measuring time differences. Finite precision causes areas of uncertainty that lie perpendicular to the LOP. At the intersection of two LOP's, the area of uncertainty takes the form of a parallelogram oriented along the angle of intersection of the LOP's. As this angle becomes more acute, the area of uncertainty becomes greater. The optimal solution occurs at 90° and will vary with geographical position for any two LOP's.

LORAN-C SIGNAL STRENGTH RESULTS.

Loran-C signal strength data was compiled from SNR data output by the receivers during flight. Representative plots are presented in figures 13 and 14. They show SNR's near 5 decibels (dB), the maximum that can be computed by the Loran receiver, for the stations in use. The stations in the GRI 9960 Chain used for navigation were Seneca, Carolina Beach, and Dana. The stations used from the GRI 8970 Chain were Dana, Malone, and Seneca. In both cases, the fourth signal (Nantucket and Baudette), which is not part of the primary triad, shows the lowest SNR. Under operational conditions, this could prevent the receiver from entering its backup mode of navigation known as master independence. In this mode, a station which becomes unusable is replaced with the fourth station in track, forming a new triad.

While this feature is intended to provide some redundancy, its use may be precluded in the flight test area by lack of signal availability. The data show that Nantucket is more likely than Baudette to serve as a suitable backup. This was expected, since Nantucket is 570 miles from the center of the flight test area and Baudette is approximately 860 miles away from the area.

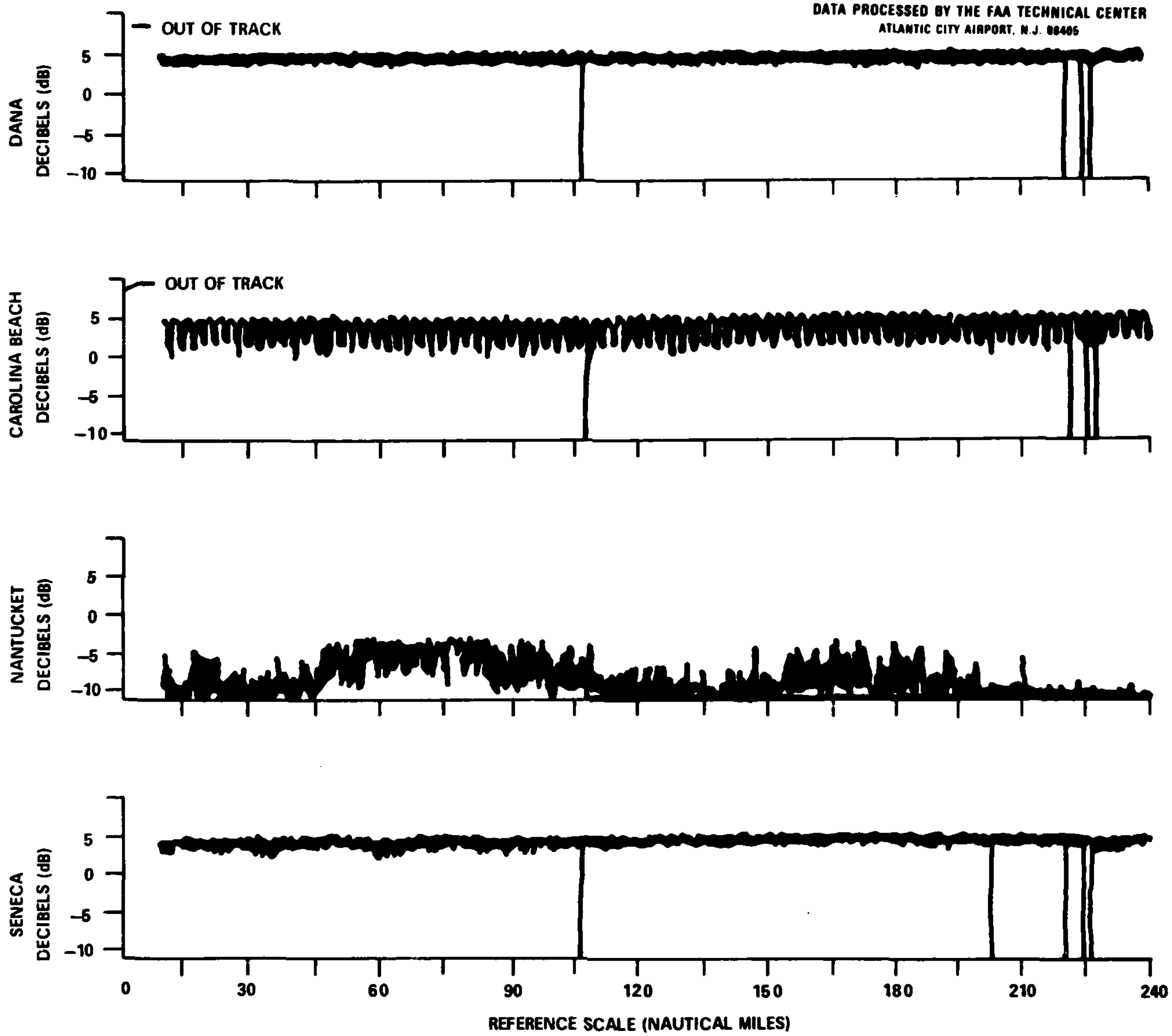
The SNR plots also show occasional out-of-track conditions which occur for one sample each. The TDL-711 continues processing through these periods for up to 8 seconds before dropping the pilot's navigation flag. During this time the last computed position is processed through a velocity filter to provide an extrapolated position estimate. One second dropouts are transparent to the user and do not noticeably affect longer-term position accuracy.

CONCLUSIONS

1. Both the Northeast United States (U.S.) Chain and the Great Lakes Chain provide adequate coverage of the flight test area with a minimum of three stations. Seneca, Carolina Beach, and Dana from the Northeast U.S. Chain, and Dana, Malone, and Seneca from the Great Lakes Chain provide adequate signal strength for position determination over the entire flight test area.

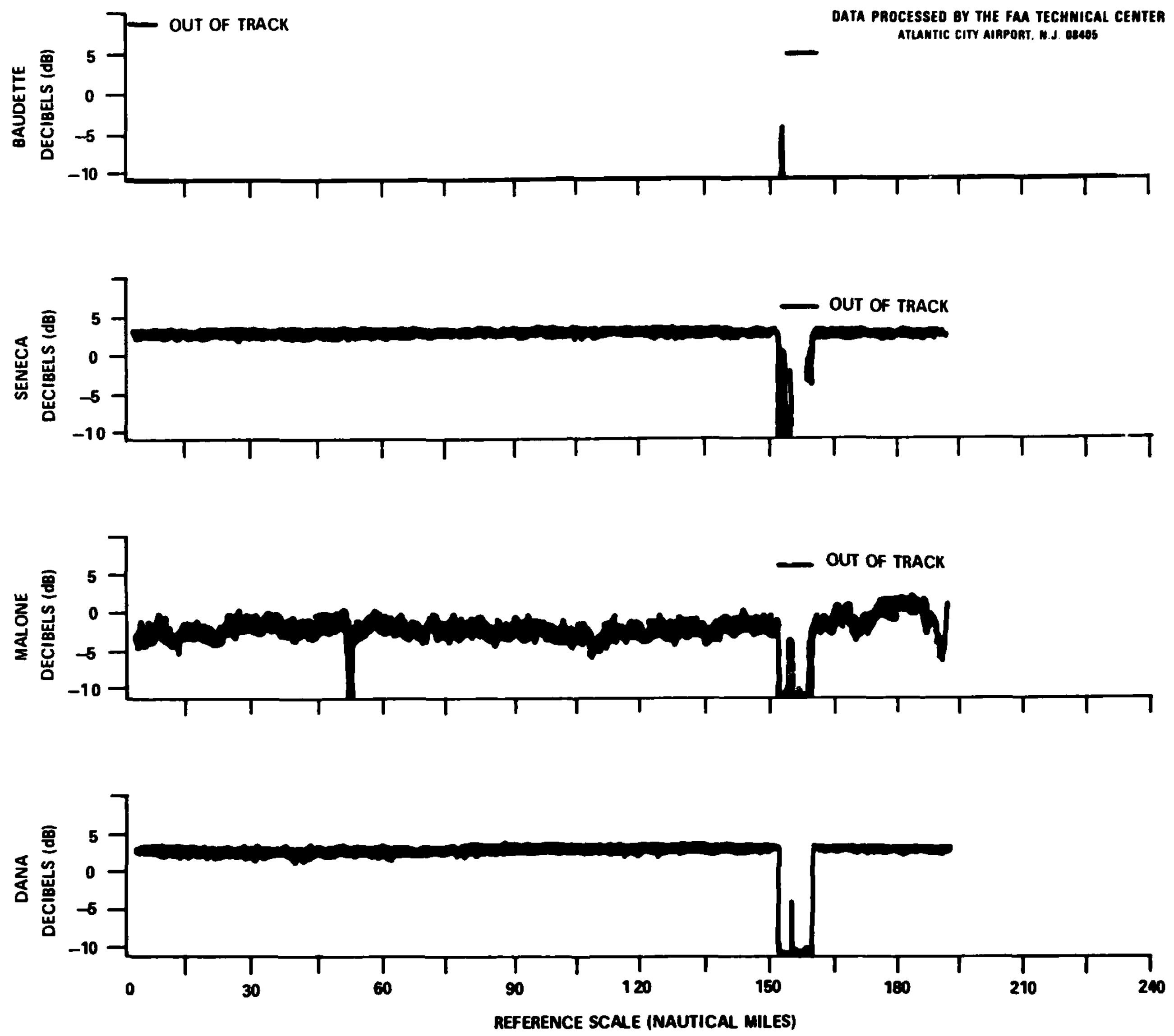
2. The fourth station in each Chain (Nantucket in the Northeast U.S. Chain and Baudette in the Great Lakes Chain) exhibited signal-to-noise ratios (SNR's) that could make it difficult or impossible to track either of these stations in portions of the flight test area, precluding their use as backup stations in either chain.

3. The flight test data supports use of the GRI 9960 Northeast U.S. Loran-C Chain and the 8970 Great Lakes Chain for en route navigation over the entire flight test



82-32-13

FIGURE 13. REPRESENTATIVE SIGNAL-TO-NOISE RATIO PLOT FOR NORTHEAST U.S. LORAN-C CHAIN



82-32-14

FIGURE 14. REPRESENTATIVE SIGNAL-TO-NOISE RATIO PLOT FOR GREAT LAKES LORAN-C CHAIN

area. The data presented meet Advisory Circular (AC) 90-45A en route criteria in all sectors and all directions of flight for crosstrack and along-track accuracy.

4. The Northeast U.S. Chain is preferred over the Great Lakes Chain for en route navigation in the flight test area because of greater accuracy. However, the Great Lakes Chain is also acceptable.

5. Two stations (Dana and Seneca) are dual rated (used on both Chains) and are used in the formation of the prime triad for each of the two Chains. An outage of either station could cause a loss of all Loran-C navigational capability in the flight test area when using the TDL-711 navigator.

APPENDIX A

CORRECTED INERTIAL NAVIGATION SYSTEM POSITION ACCURACY

LTN-51 Inertial Navigation System (INS) position errors are comprised of both linear and cyclic variations, which can combine to produce drift errors at a rate of up to 1 nautical mile (nmi) per hour. Variations due to mass imbalances, friction, and timing errors in the unit produce constant velocity and acceleration errors that degrade position accuracy. Nonlinear error terms are introduced by several sources of Schuler variations, sinusoids with a period of 84 minutes. The source of greatest Schuler error causes a maximum amplitude of 0.1 nmi, while other lesser sources contribute a total of 0.1 nmi.

Post-flight linear drift compensation is achieved by computing the difference between INS and actual position over succeeding references, and determining the per-second correction to be applied over the intervening time segment. References were chosen for high visibility from the air and because they were at known latitude and longitude. Very high frequency omnidirectional radio range and tactical air navigation aids (VORTAC's) were chosen for most of the reference points required.

Use of visual references causes some small errors in computation of the correction factor. The operational method employed was to have the copilot activate a switch when he believed he was directly over the reference. Switch position was recorded once each second with the rest of the airborne parameters. The INS position recorded at that time was used to compute the correction factor. At speeds of 200 knots for the entire flight test, an aircraft travels approximately 350 feet (0.06 nmi) per second. This is the uncertainity due to the recording method. The ability to judge position over the reference and to activate the switch was estimated introduce an error of approximately 150 feet (0.025 nmi), based on 1,000-foot altitude used for the flight test.

The sum of the errors discussed is 0.285 nmi in the worse case with the maximum Schuler effect. Also, each of the errors may occur in a positive or negative direction, and the possible error is actually ±0.285 nmi, rounded off to ±0.3 nmi for data analysis.

Data presented in table A-1 show the maximum INS drift of 0.40 nmi between INS position updates. In a perfectly linear system, the correction factor applied will eliminate all the error terms. However, the Schuler variations cause a remaining position uncertainity that may be as great as the total Schuler amplitude. Data show that, in most cases, the root sum square (rss) drift before linear correction is less than ±0.3 nmi. It should be emphasized that these data are raw differences before INS correction is applied. After correction, there is no difference between the INS computed position and the actual position of the update point.

TABLE A-1. INS DRIFT ON APRIL 19, 1980, FLIGHT

Update No.	Position Error (Actual Position) INS Position (nmi))		Drift Since Last Waypoint (nmi) Update		rss Drift (nmi)
	Northing	Easting	Northing	Easting	
1	-0.0421	-0.0088			
2	-0.1859	-0.1159	-0.1438	-0.1069	0.18
3	0.1680	-0.1946	0.3539	-0.0787	0.36
4	0.1015	0.0046	-0.0665	0.1992	0.21
5	0.1561	-0.1713	0.0546	-0.1759	0.18
6	-0.2220	-0.0325	0.3781	0.1388	0.40
7	-0.3301	-0.2547	-0.1081	-0.2222	0.25
8	-0.4200	-0.2172	-0.0901	0.0375	0.10
9	-0.2458	0.1247	0.1742	0.3419	0.38
10	-0.1861	0.1296	0.0596	0.0049	0.06
11	-0.0721	-0.0367	0.1140	-0.1663	0.20
12	-0.2161	0.0064	-0.1440	0.0431	0.15
13	-0.2627	0.1335	-0.0466	0.1271	0.14
14	-0.1918	0.2451	0.0709	0.1116	0.13
15	-0.0419	0.0187	0.1499	-0.2264	0.27

2-8

DT